

CALIFORNIA FISH and GAME

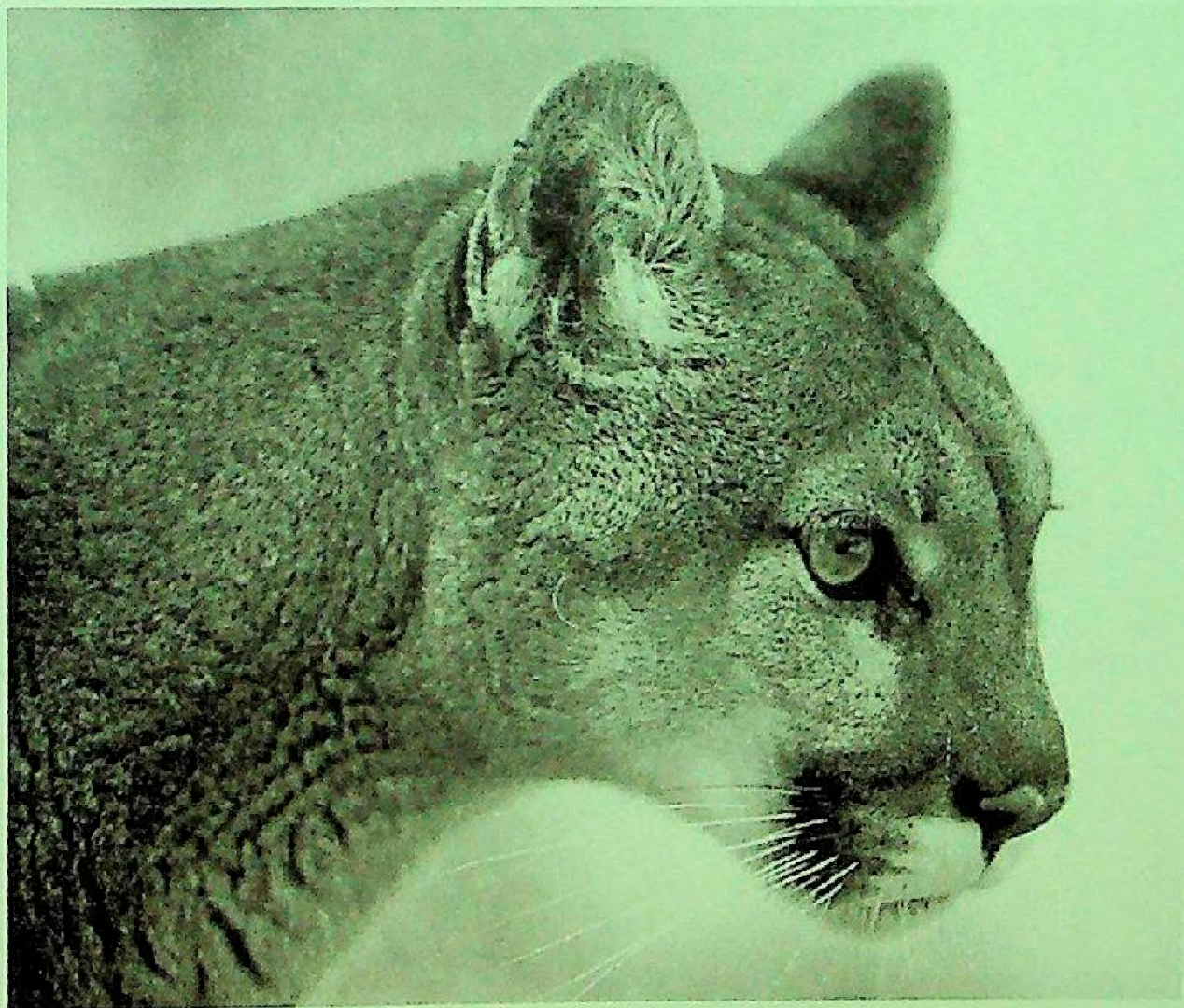


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COVER

Mountain Lion, *Puma concolor*

PHYSICAL CONDITION, MORPHOMETRICS, AND GROWTH CHARACTERISTICS OF MOUNTAIN LIONS

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We examined 564 records of mountain lions, *Puma concolor*, necropsied in California from 1976 to 1996 to describe physical condition, morphometrics, and growth characteristics. The majority of the mountain lions were in fair to excellent physical condition at the time of death. Mountain lions <1 year of age were more likely to be in poor physical condition than mountain lions 1–6 years of age. Older (>6 years) female mountain lions were more likely to be in poor physical condition than were females 1–6 years of age, but this relationship was not detected for males. Excluding lions that died of disease or debilitating injury, physical condition and body weight did not differ by cause of death, season, year (1990–1996), decade, or geographical region of California. Adult males and females differed in 13 of 16 morphological measurements and males were approximately 50% larger than females. Female mountain lions appear to complete growth by their 3rd year while male mountain lions continue to grow into their 4th year.

INTRODUCTION

Mountain lions, *Puma concolor*, being long-lived, secretive carnivores with large home ranges, are difficult to study in the wild (Quigley and Hornocker 1992). For this reason, few long-term intensive studies have been conducted on free-ranging mountain lions (Seidensticker et al. 1973, Ross and Jalkotzy 1992, Lindzey et al. 1994, Logan et al.² 1996). Consequently, large data sets that allow analyses of

¹ Current address: 1829 St. Ann Court, Carmichael, California 95608.

² Logan, K.A., L.L. Swenar, T.K. Ruth, and M.G. Hornocker. 1996. Cougars of the San Andres Mountains, New Mexico. New Mexico Department of Game and Fish. Federal Aid to Wildlife Restoration Final Report, Project W-128-R.

physical condition, morphology, and growth characteristics are rare. Data on temporal and regional patterns of the above variables are similarly sparse (Anderson³ 1983).

The California Department of Fish and Game (CDFG) has maintained a database of mountain lions necropsied in the state since 1976. Over 500 records have been collected, providing a unique opportunity to examine certain physical characteristics of mountain lions.

The objectives of this study were to: 1) examine physical condition of mountain lions in relation to sex, age, season, year, decade, region, and cause of death; 2) describe the relationship between morphological parameters and physical condition of mountain lions; 3) describe morphological measurements of adult male and female mountain lions in California; and 4) describe growth patterns of male and female mountain lions.

METHODS

We examined records of mountain lion necropsies performed from 1976 to 1996 ($n = 564$) in California. Most necropsies were performed by CDFG field biologists who recorded information on standardized forms. In 1990, a state law was enacted that required a necropsy of any mountain lion killed for pet or livestock depredation. For this reason, from 1990 to 1996 most necropsy data were from lions that were killed for depredation.

We reviewed data sheets and standardized information by coding. Data normality and homoscedasticity were determined by calculating Shapiro-Wilk statistics and F-values (Zar 1984). Appropriate nonparametric procedures (Kruskal-Wallis test, Mann-Whitney test) were substituted for their parametric counterparts when normality and homoscedasticity assumptions were not met. P -values < 0.05 were considered significant for all statistical analyses.

Persons performing the necropsies estimated mountain lion age based on tooth color and wear, pelage characteristics, and the animal's size (Ashman et al.⁴ 1983). When an estimated age range was reported, the lowest value was used for our analyses (e.g., if age was reported as 2–4 years, 2 years was used). We assigned mountain lions to 1 of 5 age classes based on the estimated age at the time of death. The age classes were: < 1 year, 1 year, 2 years, 3–6 years, and > 6 years. Animals ≥ 2 years were considered adults.

Physical condition of mountain lions was subjectively assigned to 1 of 3 categories (good, fair, poor) by the person performing the necropsy; condition assessment was made based on amount of body fat, coat condition, and general appearance. We used contingency tables (Fisher exact test) to test for associations between condition and sex and between condition and age class for all mountain lions. Contingency tables

³ Anderson, A.E. 1983. A critical review of the literature on puma (*Felis concolor*). Colorado Division of Wildlife Special Report No. 54.

⁴ Ashman, D.L., G.C. Christensen, M.L. Hess, G.K. Tsukamoto, and M.S. Wickersham. 1983. The mountain lion in Nevada. Nevada Fish and Game Department. Federal Aid to Wildlife Restoration Final Report, Project W-48-15.

were also used to test for associations between condition and region, season, cause of death, and year (1990–1996 only) for adult lions.

We examined temporal trends of mountain lion characteristics by season, year (1990–1996 only) and decade (1970s, 1980s, and 1990s). We defined seasons as winter (December–February), spring (March–May), summer (June–August), and fall (September–November).

To examine spatial differences in selected mountain lion variables, we divided California into 4 geographical regions based on county of collection. “North” contained the northwest mountain ranges and Modoc Plateau, “West” contained the north and central coast ranges, “East” contained the Sierra Nevada Range, and “South” contained the Peninsular and Transverse ranges.

We calculated and compared weight:body length ratios of lions in each of the 3 condition categories using 1-way analysis of variance (ANOVA). Tukey’s multiple comparison procedure was used to identify significant differences in weight:body length ratios by condition category.

We used the Kruskal-Wallis test to compare body weights of adult mountain lions that died during different seasons, years (1990–1996), and decades and in different regions of California. Males and females were analyzed separately. We used regression analysis to describe the relationship between body weight and chest girth and to derive a model to predict weight based on chest girth for all lions for which these data were available. Observations with residual error values greater than 3 standard deviations from the regression line were considered outliers and were omitted from the analysis. The best fitting model was selected based on examination of scatterplots of residual error terms and comparisons of adjusted coefficient of determination values for different models (Kleinbaum et al. 1988).

We compared morphological measurements between adult males and adult females to detect sex-related differences in morphology using 1-tailed Mann-Whitney tests.

We constructed growth curves for mountain lions by plotting the mean body weight for each age category against estimated age in years for both males and females.

RESULTS

We categorized cause of death for all 564 mountain lions: depredation (77%), roadkill (9%), disease or debilitating injury (4%), public safety (4%), not reported (4%), and other (2%). For some analyses, the “not reported” and “other” categories were omitted.

Physical condition was recorded for 309 mountain lions killed for depredation and 59 lions that died of other causes. Of these, 3% of the mountain lions killed for depredation were classified as being in “poor” physical condition in contrast to 25% of the lions that died of other causes. When disease or debilitating injury were excluded from the analysis, 6% of the non-depredating mountain lions were classified as being in poor physical condition.

Ages were estimated for 352 mountain lions. Thirty-one (17 males, 14 females) were <1 year old, 63 (26 males, 37 females) were 1 year old, 85 (53 males, 32 females) were 2 years old, 142 (96 males, 46 females) were 3–6 years old, and 31 (18 males,

13 females) were >6 years old. The maximum estimated age of mountain lions in this sample was 10 years (3 males, 6 females).

Mountain lions <1 year old were more likely to be in poor physical condition than mountain lions 1–6 years old (Fisher 1-tailed $P < 0.001$). A similar proportion of male and female mountain lion kittens (approximately 30%) was in poor physical condition. Female mountain lions >6 years old were more likely to be in poor condition than females 1–6 years old (Fisher 1-tailed $P < 0.001$). An association between old age and poor physical condition was not apparent in male mountain lions (Fig. 1).

Physical condition of adult mountain lions did not differ by season, year (1990–1996), decade, geographical region, or cause of death (exclusive of lions that died of disease or debilitating injury) ($P > 0.05$). Mean weights of adult mountain lions did not differ by season, year (1990–1996), decade, or geographical region for males or females ($P > 0.05$).

Weight:length (W:L) ratios of mountain lions differed significantly in each condition class ($F = 48.58$; $df = 2, 409$; $P < 0.001$). Mean W:L ratios were 0.36 (SD = 0.09), 0.29 (SD = 0.07), and 0.19 (SD = 0.07) for mountain lions in good, fair, and poor physical condition (Fig. 2).

We found a significant relationship between body weight and chest girth for all mountain lions ($r^2 = 0.82$, $P < 0.001$, $n = 416$). A power equation provided the best fit of the data: $y = 0.0031x^{2.2471}$ where y = body weight (kg) and x = chest girth (cm) (Fig. 3).

Adult male mountain lions had higher values than adult females for all morphological measurements except shoulder height, front foot length, and rear foot length (Table 1). Growth curves indicated that male mountain lions continue to grow into their 4th year and that females cease growth at just under 3 years of age (Fig. 4).

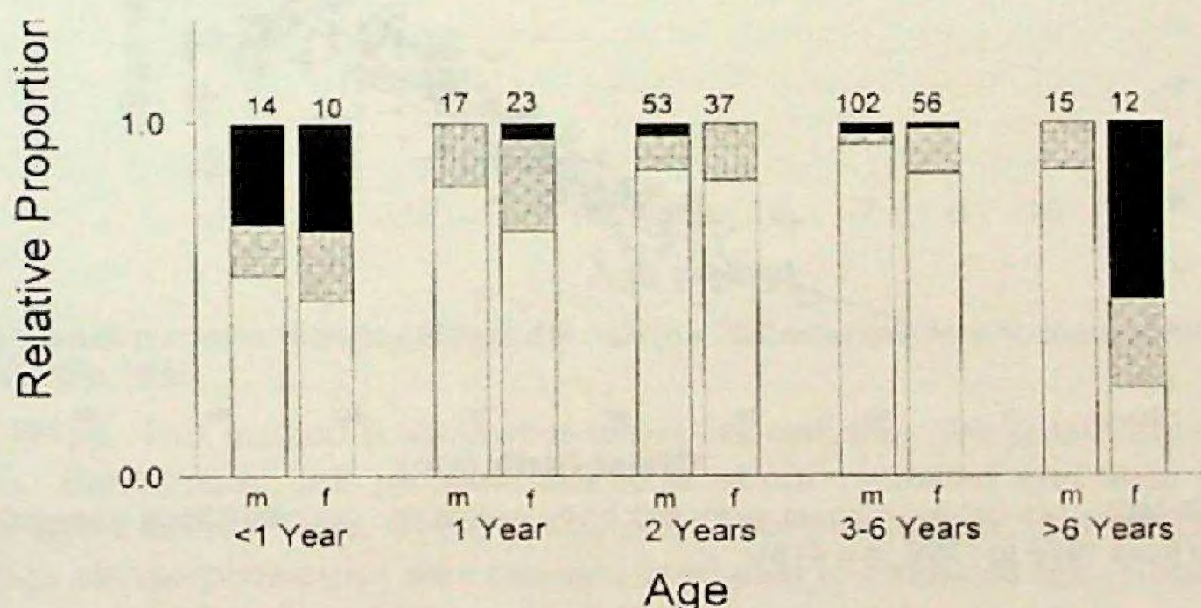


Fig. 1. Physical condition by sex and age class of mountain lions necropsied in California from 1976 to 1996. Numbers above bars are sample sizes for each class. Black fill in bars indicates poor condition, gray fill is fair condition, and white is good condition.

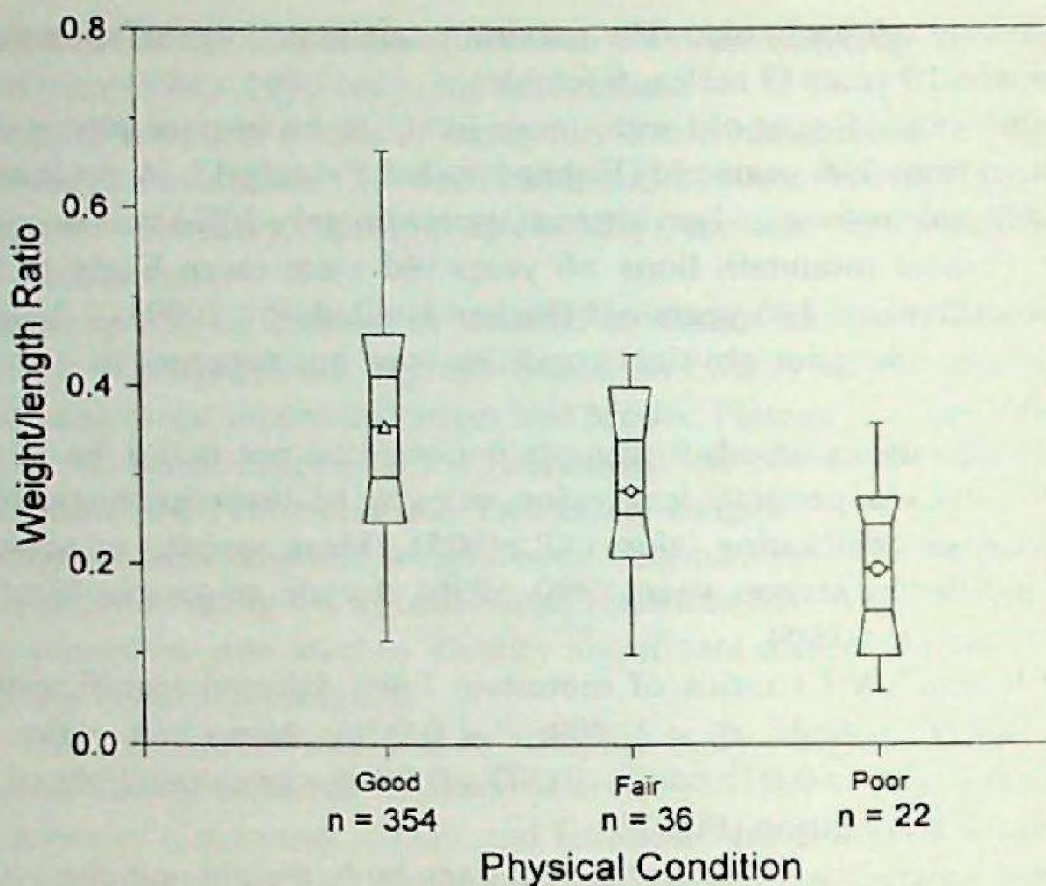


Fig. 2. Box-whisker plots illustrating the relationship between weight:length ratios and physical condition classes for mountain lions necropsied in California from 1976 to 1996. Horizontal lines mark the minimum, maximum, 10th, 25th, 50th, and 90th percentile points.

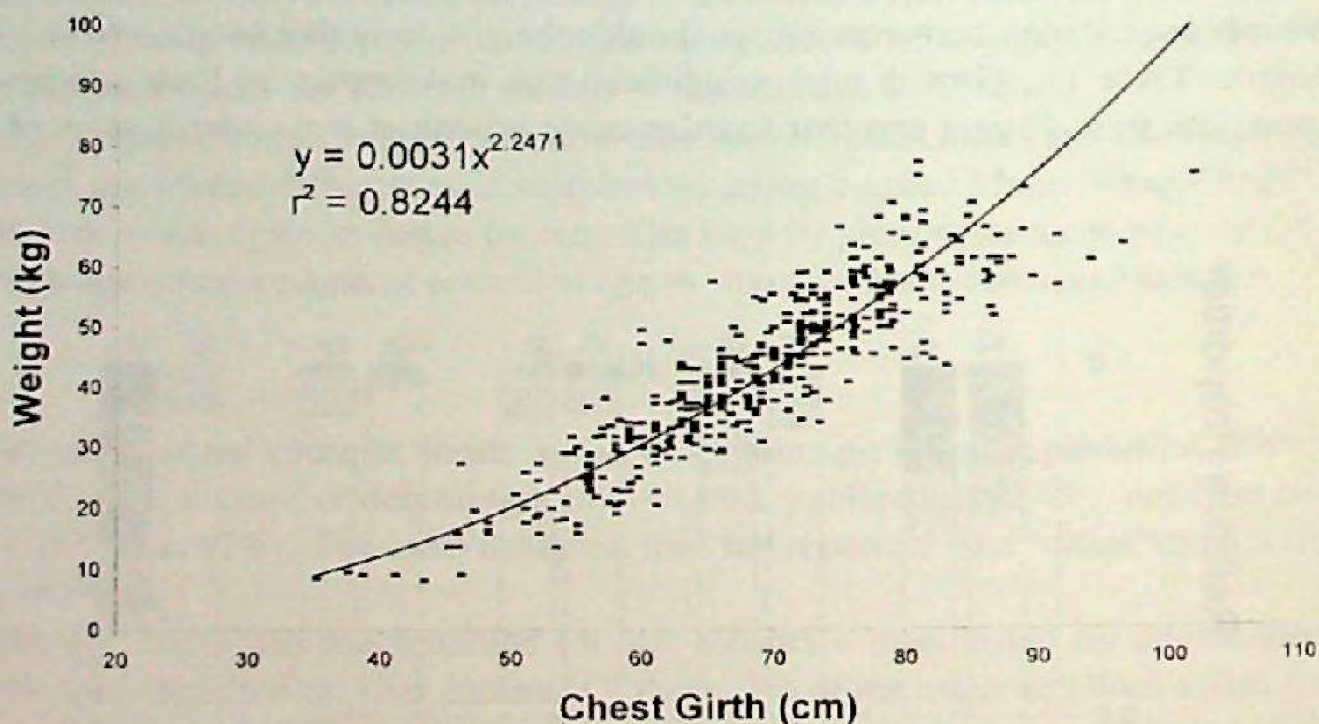


Fig. 3. Relationship between chest girth and body weight for mountain lions necropsied in California from 1976 to 1996 (n = 416).

DISCUSSION

Currently, no method for accurate age determination of mountain lions is available; most investigators use guidelines similar to those outlined by Ashman et

Table 1. Morphological measurements of adult mountain lions necropsied in California from 1976-1996. Values reported in centimeters unless otherwise indicated.

Parameter	Males			Females		
	Mean	SD	N	Mean	SD	N
Body weight (kg)	53.45	8.53	158	35.81	7.68	80
Tail length	74.99	6.91	176	68.90	8.26	86
Body length	130.48	9.89	178	118.35	12.84	85
Chest girth	75.67	7.23	168	64.55	9.77	83
Shoulder height	65.16	7.24	28	60.09	6.67	14
Head width	18.34	7.68	30	14.24	2.71	13
Head length	24.47	3.08	31	22.80	1.97	13
Neck circumference	41.88	4.48	31	34.25	6.95	13
Front pad length	4.63	0.82	32	3.96	0.47	16
Front pad width	6.04	0.62	33	5.06	0.47	16
Front foot length	9.35	2.20	28	9.41	2.73	12
Front foot width	8.59	1.40	28	7.67	1.10	12
Rear pad length	4.21	1.00	32	3.77	0.35	15
Rear pad width	5.10	0.51	32	4.53	0.40	15
Rear foot length	9.09	0.99	27	9.09	1.61	10
Rear foot width	7.03	0.93	28	6.28	0.81	11



Fig. 4. Growth curves for male ($n = 269$) and female ($n = 164$) mountain lions necropsied in California from 1976 to 1996.

al.² (1983). This method is somewhat subjective and, thus, the possibility for error exists. Furthermore, it is probable that some of our estimated ages were partially based on the animal's size. These limitations can be problematic, particularly where weights and morphometrics are examined in relation to estimated age. Nonetheless, this is currently the most widely-used method for estimating mountain lion age (Ross and Jalkotzy 1992, Lindzey et al. 1994, Logan et al.² 1996).

Mountain lion kittens (<age 1) were more likely to be in poor physical condition than lions 1–6 years of age. This was similar to findings in lynx, *Felis lynx*, where

younger animals had lower percent bone marrow fat than adults (Stewart⁵ 1974). Poorer body condition of young animals may reflect their inefficiency in catching prey and the increased nutritional demands of growth. Alternatively, young lions in poor condition may be more prone to depredation than those in good condition and, thus, young lions in poor condition might be over-represented in this data set.

Old female mountain lions were in poorer condition than female lions 1–6 years of age, but we did not detect this relationship in male mountain lions. Roelke et al.⁶ (1985) reported a similar relationship between old age and poor physical condition in female lions. Physical condition of female lions may deteriorate more markedly with age than that of male lions as a result of the increased physiological costs of bearing and rearing young.

Seasonal, annual, and regional differences in body weight have been reported for medium to large-sized carnivores (Windberg et al. 1991, Durner and Amstrup 1996). However, in this study neither body weight nor physical condition varied with season, year, decade, or geographical region of California.

Body weight:body measurement ratios have been used in several wildlife species to quantify physical condition of individual animals (Robinson 1960, Bailey 1968). In our study, subjective assessment of physical condition corresponded well with body weight:body length ratios.

As in other wildlife species (Berger and Peacock 1988, Durner and Amstrup 1996, Millspaugh and Brundige 1996), chest girth of mountain lions was found to correlate well with body weight. A correlation between chest girth and body weight of mountain lions was also reported by Currier⁷ (1979). This finding may be useful in field situations where equipment for weighing mountain lions may not be available.

We found evidence for differential growth rates and age at maturity for male and female mountain lions. In a model of mass growth for California mountain lions, Maehr and Moore (1992) estimated that the growth period for female lions was 2.3 years and for males 3.4 years. Robinette et al. (1961) developed a growth curve for mountain lions from 6 records of known-age individual animals, several estimated-age individuals, and the probable weights by sex at maturity. In constructing his curve, he assumed that females cease growth at 2.5 years and males at 3 years. Based on 19 cranial and mandibular measurements, Gay and Best (1996) reported that female mountain lions grow until they are 5–6 years old, whereas males grow until 7–9 years old. Our growth curve indicates that females cease growth at approximately 3 years while males continue to grow until their 4th year. We found that the weight of female mountain lions decreases with age after 5 years, a finding

⁵ Stewart, R.R. 1974. Age distribution, reproductive biology and food habits of Canada lynx (*Lynx canadenses* Kerr) in Ontario. M.S. Thesis, University of Guelph, Ontario, Canada.

⁶ Roelke, M.E., E.R. Jacobson, G.V. Kollias, and D.J. Forrester. 1985. Medical management and biomedical findings on the Florida panther (*Felis concolor coryi*). Annual Report to the Florida Game and Freshwater Fish Commission, Gainesville, Florida, USA.

⁷ Currier, M.J.P. 1979. An age estimation technique and some normal blood values for mountain lions (*Felis concolor*). Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado, USA.

also reported for female lions in Florida (Maehr and Moore 1992). Male lions were approximately 50% larger than females based on body weight, similar to mountain lions in other areas (Anderson³ 1983).

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LIMITATIONS OF NUCLEAR MAGNETIC RESONANCE ANALYSIS OF FECAL BILE FOR TAXONOMIC IDENTIFICATION OF CONTEMPORARY AND EXTINCT MAMMALS

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We used nuclear magnetic resonance (NMR) to analyze both distilled water- and alcohol-extracted bile from feces of 11,000–40,000-year-old extinct as well as contemporary mammals. Some samples did not yield sufficient concentrations for adequate examination. The NMR spectral pattern from fecal bile was not consistent enough to provide a reliable signature for species identification. Secondary bile, from gut flora alteration of primary bile, accounts for some of the limitation.

INTRODUCTION

Ten years ago, we developed a proton nuclear magnetic resonance (NMR) technique for identifying primary bile from gall bladders for forensic use (Theis et al. 1988). This method has proven reliable in the identification of bile even after the bile was exposed to extreme physical conditions (freezing, boiling, long-term storage). The diagnostic spectral range that brackets the components of bile extends from 2.8 to 4.2 ppm chemical shift (Theis et al. 1988). We have also investigated the usefulness of this technique in determining the species of origin of feces based upon analysis of bile extracted from fecal samples of contemporary and extinct mammals. Herein, we report the complications of spectral analysis and limitations of the methods used.

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METHODS

NMR Spectroscopy

Proton NMR spectra were obtained on a Nicolet² NM-500 spectrometer operating at a field of 11.75T for ¹H observation at 500 MHz. Spectra were collected with a sweepwidth of 8 KHz with 8 K complex points and a 2-second recycle time. Generally, 100–200 scans were collected for each sample and a 1 Hz linebroadening was used in the exponential apodization of the raw data. The residual water peak was suppressed with a low power presaturation pulse. Peak shifts were referenced to 2,2-dimethyl-5-silapentane-sulfonate.

Sample Collection

Fecal samples were collected from 16 contemporary and 5 extinct mammals (Table 1). The extinct mammals lived on what is now the Colorado Plateau in the southwestern United States 11,000–40,000 years ago (Mead and Agenbroad 1992).

Fecal samples of known identity, either collected from fresh deposits (contemporary species) or in association with skeletal remains (extinct species) or identified by shape and size (extinct species), were initially submitted in sealed bags to develop a signature pattern for each species. Later, other samples, whose identity was known only to the collector, were submitted as “unknowns” to test the reproducibility of the technique. A total of 108 samples from the 21 contemporary and extinct mammals were analyzed by proton NMR.

Sample Preparation

Fecal material was distilled-water extracted, in a manner similar to that used for bile from gall bladders (Theis et al. 1988). Lyophilized samples were re-solubilized with deuterium oxide (²H₂O) at a concentration of 5 mg/ml of solvent. Fecal bile was also extracted with water and alcohol using a modified technique reported by Setchell et al. (1983). Approximately 7 gm of fecal material was added to 70 ml of distilled water in a blender and blended for 5 minutes. Then, 240 ml of 100% methanol was added and blended for an additional 5 minutes. The slurry was poured into an Erlenmeyer flask and refluxed for 2 hours on a heated magnetic stirrer platform. The refluxed sample was poured into centrifuge tubes and spun at 3500 RPM for 10 minutes. The supernatant was filtered through a Nalgene² filter unit (Catalog no. 245), placed in a sterile flask, and heated to 70°C to boil off the methanol. The remaining liquid was lyophilized and 5 mg was resuspended in 1 ml of deuterated chloroform for NMR spectroscopy.

² The use of trade names does not imply endorsement by the California Department of Fish and Game.

Table 1. Contemporary and extinct mammals from which fecal bile samples were collected for nuclear magnetic resonance analysis.

<u>Species</u>	<u>Collection Location</u>
Contemporary	
Cow, <i>Bos taurus</i>	Cowboy Cave, Utah, USA
Horse, <i>Equus caballus</i>	Cowboy Cave, Utah, USA
Burro, <i>Equus asinus</i>	Grand Canyon, Arizona, USA
Bighorn sheep, <i>Ovis canadensis</i>	Tinajas Atlas Mountain, Arizona, USA and Bishop, California, USA
Muskox, <i>Ovibos moschatus</i>	University of Arkansas, Little Rock, Arkansas, USA
Mule deer, <i>Odocoileus hemionus</i>	Saw Mill Creek, California, USA
Elk, <i>Cervus elaphus</i>	Jasper, Wyoming, USA
Bison, <i>Bison bison</i>	Custer State Park, South Dakota, USA
Mountain goat, <i>Oreamnos americanus</i>	Denver Zoological Garden, Denver, Colorado, USA
African elephant, <i>Loxodonta africana</i>	Ngorongoro National Park, Tanzania and Tsavo National Park, Kenya
Indian elephant, <i>Elephas maximus</i>	Circus
Pygmy rabbit, <i>Sylvilagus idahoensis</i>	U.S. Sheep Lab, Idaho, USA
Nuttall's cottontail, <i>Sylvilagus nuttallii</i>	Desatoya Mountains, Nevada, USA
Hare, <i>Lepus</i> sp.	Anamex site, Pima County, Arizona, USA and Horse Canyon, Snake Mountains, Nevada, USA
Blacktail prairie dog, <i>Cynomys ludovicianus</i>	Black Hills, South Dakota, USA
Pika, <i>Ochotona princeps</i>	Virginia Basin, Colorado, USA, Cedar Breaks, Utah, USA, and Ruby Mountains, Nevada, USA
Extinct	
Mammoth, <i>Mammuthus</i> sp.	Bechan Cave, Grobot Grotto, and Mammoth Alcove, Utah, USA
Mountain goat, <i>Oreamnos harringtoni</i>	Stanton's and Tse'an Bida caves, Arizona, USA
Shrub ox, <i>Euceratherium collinum</i>	Bechan Cave and Grobot Grotto, Utah, USA
Musk ox, <i>Symbos</i> sp.	Frozen carcass, Alaska, USA
Sloth, <i>Nothrotheriops shastensis</i>	Bechan, Gypsum, and Rampart caves, Utah, Nevada, Arizona, USA

RESULTS

Individual peaks in NMR spectra between 2.8 and 4.2 ppm cannot be assigned to specific chemical configurations; however, previous studies indicate that they represent regions where bile components appear (Theis et al. 1988).

Within the same species, differences in location and, probably, diet do not appear to influence spectral patterns. This is demonstrated by the nearly identical spectra

from the contemporary African elephant, *Loxodonta africana*, from Ngorongoro Crater National Park, Tanzania (Fig. 1A) and from Tsavo National Park, Kenya (Fig. 1B). This similarity in intraspecific spectra extends to extinct mammals also, as exemplified by bile in mammoth feces collected in 2 different locations (Fig. 1C and D).

In some instances it was possible to differentiate between species based on NMR results, but in other cases different species exhibited considerable overlap in NMR spectra. The contemporary African elephant (Fig. 1A and B) and extinct mammoth (Fig. 1C and D) were easily distinguishable by distinct spectral differences at 3.3–3.5 ppm and at 4.1 ppm. However, the extinct shrub ox, *Euceratherium collinum*,

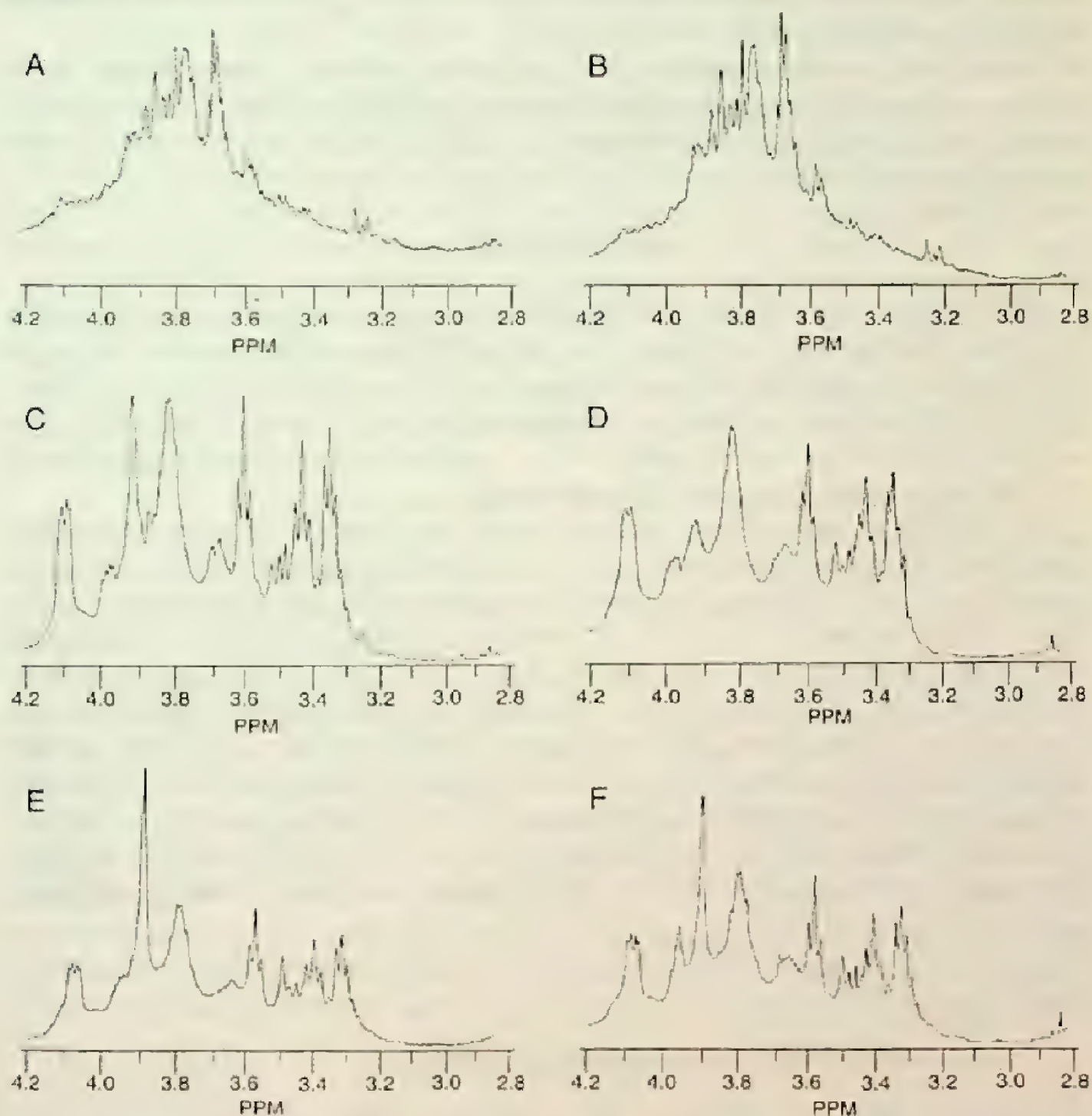


Figure 1. Fecal bile spectra from A) African elephant, Ngorongoro Crater National Park, Tanzania; B) African elephant, Tsavo National Park, Kenya; C) extinct mammoth, Bechan Cave, Utah, USA; D) extinct mammoth, Mammoth Alcove, Utah, USA; E) extinct shrub ox, Grobot Grotto, Utah, USA; F) extinct mountain goat, Stanton Cave, Arizona, USA.

and extinct mountain goat, *Oreamnos harringtoni*, had similar NMR spectra and could not readily be identified (Fig. 1E and F). Even when additional samples from these 2 species were examined, the slight variations in spectral patterns were not consistent enough to be used for identification.

Although mammoth bile was distinct over most of the NMR spectrum, the region from 3.8 to 4.0 ppm was variable enough that it could not be used to distinguish mammoth bile (Fig. 1C and D) from shrub ox (Fig. 1E) and extinct mountain goat (Fig. 1F) bile. The 3 consecutive peaks of ever increasing height between 3.8 and 4.0 ppm that were present in some mammoth samples (Fig. 1D), and that appeared useful in separating mammoths from the other 2 extinct species, were not present in all mammoth bile (Fig. 1C).

A final problem that occurred in the analysis was that bile extraction from feces was not uniform; some samples produced adequate bile concentrations (Fig. 1), whereas others produced very little material and, hence, did not provide a usable spectral pattern (Fig. 2).

DISCUSSION

Bile obtained from the gall bladder differs in several ways from that obtained from feces; this accounts for the success of the NMR in identifying taxonomic origin from the bile, but the lack of success in identification from feces. Two of these factors are the influence of bacteria in the gut on the structure of the bile molecules and the relative degree of bile adsorption by certain plant substances in the diet of the herbivores whose feces were bile extracted.

In the first of these effects, bacteria in the gut alter the structure of the bile molecule, creating several secondary biles (Korpela et al. 1986). Each mammal usually has 1 or 2 primary bile molecules made from cholesterol and usually hydroxylated at the 3, 7, and/or 12 position (Haslewood 1964). In addition, mammalian bile is conjugated with the amino acids glycine or taurine, or both (Haslewood and Wootten 1950). Bile from the gall bladder contains a high concentration of the primary bile molecule(s) which dominates the NMR spectral signal. However, when the primary bile is deposited in the small bowel, it is subjected to the action of the bacterial flora (Haslewood 1964, Korpela et al. 1986). As each of the resultant biles may be in different concentrations in the fecal stream, the feces of a single species may have different NMR signals from time to time. In addition,

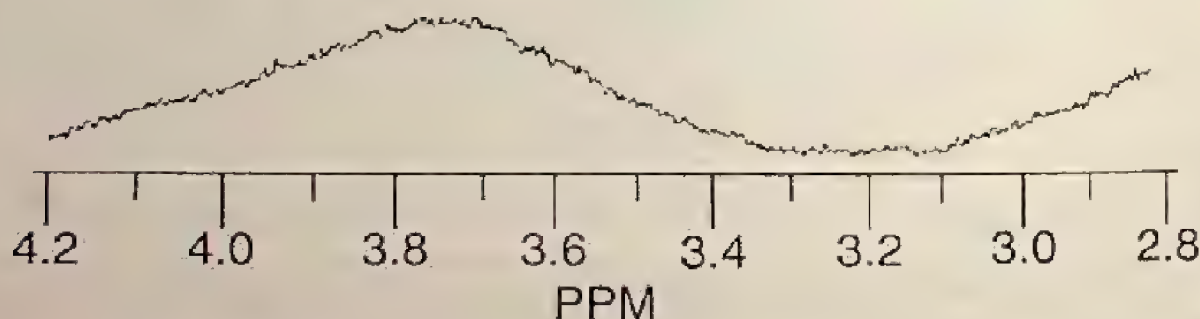


Figure 2. Fecal bile NMR spectra from mule deer, *Odocoileus hemionus*, Saw Mill Creek, California. Poor extractability of this fecal sample produced this useless pattern.

each mammal with a similar gut flora could produce from its slightly different primary bile, similar secondary biles, thus giving nearly identical NMR patterns (Setchell et al. 1983). The more similar the primary biles of 2 species are, the more likely the secondary biles will also be similar (Haslewood 1964).

This is reflected in the results of the fecal bile analysis of the shrub ox and the extinct mountain goat, which suggests that these 2 extinct mammals had similar or identical primary bile molecules. However, until frozen carcasses with gall bladders containing bile are found and analyzed, the primary bile structure of these 2 mammals will remain unknown. The composition of the gut flora is also unknown for these extinct herbivores.

The second factor affecting the NMR spectrum of fecal bile is differential adsorption by lignin, a constituent of the grass and shrubs in the diet of herbivores (Eastwood and Hamilton 1968). Intestinal pH may influence the extent to which bile salts are bound to the lignin (Eastwood and Hamilton 1968). In the more alkaline terminal portions of the large intestine, bile salts may be less tightly bound to lignin and yet not be reabsorbed by the mammal due to the material being beyond the area where bile salt resorption occurs (Eastwood and Hamilton 1968). Such bile salts could be passed with the feces but leached out of the fecal material by moisture or decayed by bacterial action. Thus, some of the poor extraction of bile salts from the 11,000–40,000-year-old feces could have been due to loss through weathering or soil bacterial action. Other samples, protected from weathering influences and with limited bacterial degradation, yielded better extracts by the rather gentle methods used.

There are more exhaustive methods described for extraction of bile acids (Korpela et al. 1986) that are claimed to be mild enough not to alter the composition of the fecal bile. If these techniques were used on the fecal samples, it is possible that better quantitative extractions would result. Whether these would yield better taxonomic discrimination is unknown.

When perfected, the techniques presented here may allow identification of fossil and subfossil remains recovered from arid environs of the American Southwest, Mongolia, China, South America, and Australia. Aside from examining paleontological curiosities, NMR analysis of dried dung from caves and shelters will help federal agencies (at present, primarily the U.S. National Park Service) to evaluate and inventory their non-renewable resources. Identification of fecal deposits (in excess of 300 m³ from 1 cave in Utah; Mead and Agenbroad 1992) will broaden our understanding of climatic and human-induced change of arid lands. Knowledge of the recent past environments and grazing potential for herbivores will enhance the ability of federal and state agencies to manage public lands (Owen-Smith 1988).

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SPLITTAIL FECUNDITY AND EGG SIZE

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Fecundity and egg size of splittail, *Pogonichthys macrolepidotus*, are described from 17 specimens collected from February to April 1996. Splittail included in the study ranged from 216 to 328 mm standard length and were sampled from a broad area of their distribution. Ovaries accounted for a mean of 13.2% of total body weight. Splittail length accounted for nearly 40% of the variation in gonadosomatic index. Mean egg diameter was 1.2 mm and ranged from 1.0 to 1.5 mm. Egg size and splittail length were not related. Fecundity ranged from 28,416 to 168,196 ova. Mean relative fecundities were 261 ova/mm standard length and 163 ova/g total weight. One earlier study found slightly lower estimated fecundity, whereas another estimated fecundity to be significantly higher.

INTRODUCTION

The splittail, *Pogonichthys macrolepidotus*, is a cyprinid endemic to the Sacramento-San Joaquin Estuary. It is relatively large (maximum length about 400 mm) and long lived (age >5 years) for a cyprinid (Moyle 1976, Daniels and Moyle 1983). Splittail are omnivorous and tolerant of relatively high salinity (Caywood¹ 1974, Young and Cech 1996). A strong positive relationship exists between year-class strength of splittail and freshwater outflow in the estuary (Daniels and Moyle 1983, Sommer et al. 1997). Although the splittail possesses life history traits well suited for the highly variable estuarine environment, they are currently a candidate species pursuant to the U.S. Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 1994).

Splittail prefer shallow, tidal freshwater, and low-salinity habitats typical of Suisun Marsh, Suisun Bay, and the Sacramento-San Joaquin Delta (Meng and Moyle 1995). From March to May, adults migrate from Suisun Bay and the delta upstream to spawn in flooded terrestrial habitats (Caywood¹ 1974, Sommer et al. 1997).

¹ Caywood, M.L. 1974. Contributions to the life history of the splittail *Pogonichthys macrolepidotus* (Ayers). M.S. Thesis, California State University, Sacramento, California, USA.

Splittail eggs are adhesive (Caywood¹ 1974) and are deposited on substrates in clusters (Wang² 1986). Juveniles migrate or are washed downstream by river flows into the shallow, highly productive areas of the lower estuary, such as Suisun Bay and Suisun Marsh. Both male and female splittail mature at 180–200 mm standard length (SL) (Caywood¹ 1974, Daniels and Moyle 1983).

Recent studies of splittail have focused on population status and geographic distribution (Meng and Moyle 1995, Sommer et al. 1997) and physiological tolerances (Young and Cech 1996). The reproductive capacity of splittail, measured here as fecundity, has only received limited study by Caywood¹ (1974) and Daniels and Moyle (1983). These studies were based on small sample sizes ($n = 8$ for Caywood and $n = 20$ for Daniels and Moyle) and produced different results. For these reasons, we chose to re-examine the fecundity and egg size of splittail during the 1996 spawning season and compare our findings with those of the 2 earlier studies.

METHODS

Collection and Processing

From 28 February to 2 April 1996, we collected 17 female splittail from a broad geographical area (Fig. 1). Gill nets captured 12 at Clifton Court Forebay and 2 at Sherman Lake. Hook and line captured 2 at Miller Park and 1 at Walnut Grove. All fish were immediately dispatched and placed on ice, then frozen later in the day.

Frozen splittail were defrosted, measured to the nearest millimeter SL and weighed (TW) to the nearest 0.1 gram. Ovaries were removed, individually weighed to the nearest 0.1 g and preserved in 10% formalin. Total ovary weight (TOW) was the sum of right and left ovary weights.

Egg Size, Gonadosomatic Index, and Fecundity

Sizes of 10 randomly selected ova from each of 15 splittail were measured to the nearest 0.1 mm with an ocular micrometer on a binocular dissecting microscope. Egg size of the remaining 2 splittail could not be measured because of poor ovary preservation. The longest axis of each ova was measured because ova were not round. We determined gonadosomatic index (GSI) by expressing TOW as a percentage of total body weight (TW): $GSI = 100(TOW/TW)$.

Total fecundity was estimated by counting the number of ova in 3 weighed subsamples (anterior, median, and posterior), calculating mean number of ova per gram, and multiplying the mean by the total preserved ovary weight. Relative fecundity was expressed as the number of ova/mm SL or the number of ova/g TW.

² Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters. California: A guide to the early life histories. Technical Report No. 9, prepared for the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary.

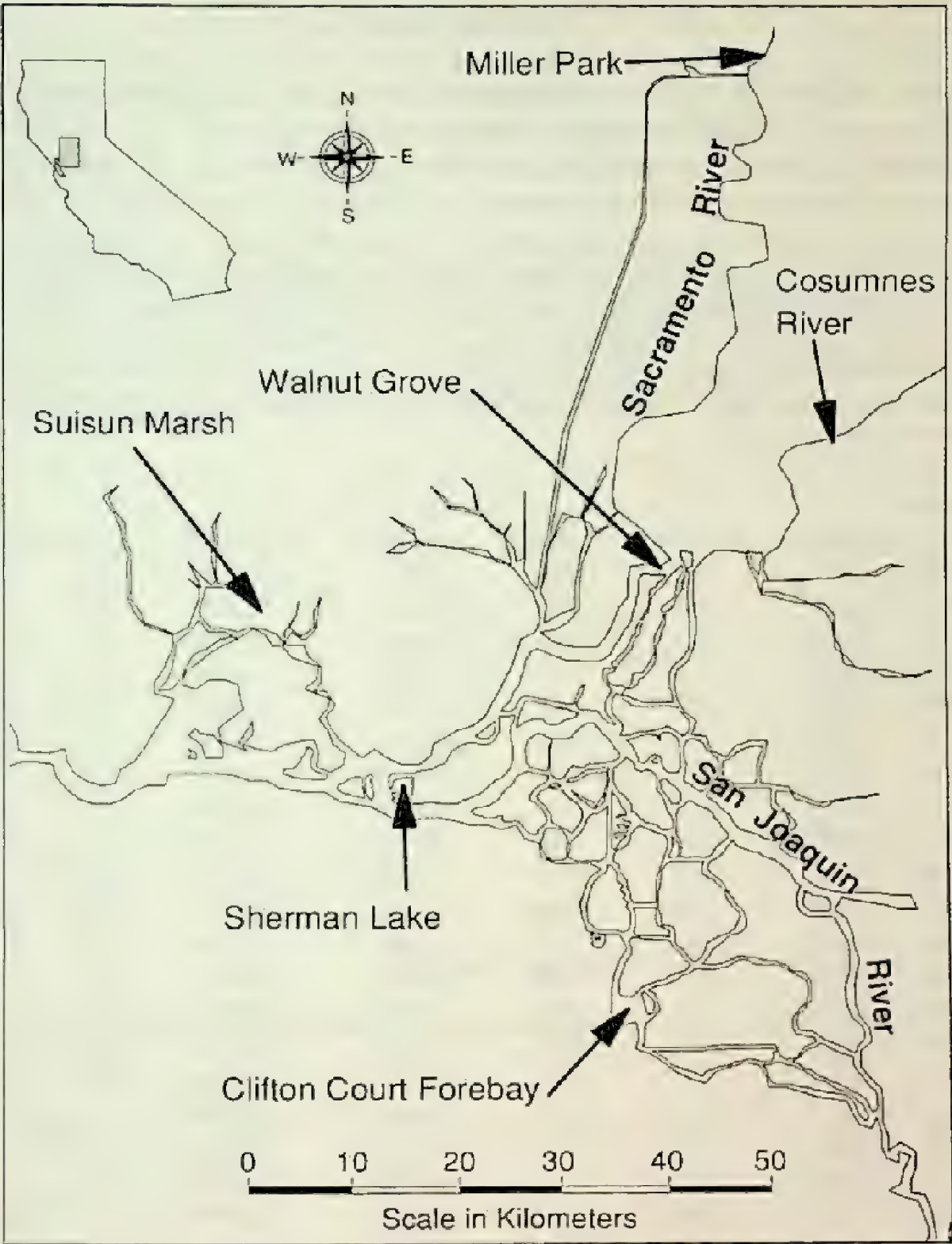


Figure 1. Map of the Sacramento-San Joaquin Estuary showing splittail sampling locations.

Data Analysis

Simple linear regression analyses were used to determine if egg size, GSI, and fecundity varied as functions of length and if fecundity was a function of total weight. Plots of fecundity on length and total weight indicated that each was an exponential function, so these variables were log transformed prior to regression analyses. A paired t-test was used to test for consistent weight asymmetry between left and right ovaries.

RESULTS

Mature female splittails collected ranged from 216 to 328 mm (mean = 264, SD = 30.6, $n = 17$). Egg size ranged from 1.0 to 1.5 mm (mean = 1.2, SD = 0.10, $n = 150$) (Table 1), but did not vary with female length ($r^2 = 0.13$, $P > 0.05$) (Fig. 2). Ovaries accounted for up to 20.3% (mean = 13.2, SD = 3.23, $n = 17$) of TW (Table 1).

Table 1. Summary data of all splittail examined for fecundity from the current study, Caywood¹ (1974), and Daniels and Moyle (1983). Locations are: WG—Walnut Grove, CCF—Clifton Court Forebay, MP—Miller Park, SL—Sherman Lake, CR—Cosumnes River (Caywood¹ 1974), and SM—Suisun Marsh (Daniels and Moyle 1983). Measurements in mm fork length (FL) (Caywood¹ 1974) were transformed into mm standard length (SL) for statistical comparison: $SL = 0.92FL - 12.08$, $r^2 = 0.99$, $P < 0.05$, $n = 17$.

Collection				Ovary			Egg
date	Location	SL (mm)	TW (g)	weight(g)	Fecundity	GSI	size(mm)
2/09/96	WG	273	503	69.00	110,600	13.6	1.25
2/21/96	CCF	246	343	33.50	51,491	9.7	1.12
2/21/96	CCF	328	744	151.40	168,196	20.3	—
2/21/96	CCF	250	339	26.20	28,416	7.7	1.10
2/21/96	CCF	270	481	55.40	45,085	11.5	1.11
2/21/96	CCF	297	642	94.00	97,660	14.6	1.34
2/21/96	CCF	315	644	104.30	113,898	16.1	—
2/21/96	CCF	245	309	36.60	44,960	11.8	1.26
2/21/96	CCF	258	409	50.30	53,590	12.2	1.27
2/21/96	CCF	283	504	77.20	81,776	15.3	1.30
2/21/96	CCF	227	266	35.50	67,210	13.3	1.12
2/21/96	CCF	250	336	25.60	52,744	7.6	1.29
2/21/96	CCF	274	485	84.30	74,655	17.4	1.33
3/12/96	MP	231	259	35.70	39,911	13.7	1.28
3/12/96	MP	294	558	76.60	94,123	14.8	1.28
4/02/96	SL	249	302	44.70	53,900	11.8	1.22
4/02/96	SL	216	211	24.90	35,609	—	1.28
2/06/74	CR	313	—	83.87	54,555	—	—
2/06/74	CR	323	—	90.93	73,185	—	—
2/06/74	CR	300	—	75.49	75,589	—	—
2/06/74	CR	290	—	64.40	48,062	—	—
2/06/74	CR	287	—	55.54	44,802	—	—
2/06/74	CR	287	—	61.27	43,211	—	—
2/06/74	CR	263	—	28.97	25,991	—	—
2/06/74	CR	242	—	20.90	23,177	—	—
—	SM	302	—	—	265,954	—	—
—	SM	260	—	—	203,385	—	—
—	SM	232	—	—	137,491	—	—
—	SM	258	—	—	153,359	—	—
—	SM	249	—	—	154,973	—	—
—	SM	223	—	—	93,626	—	—
—	SM	248	—	—	103,020	—	—
—	SM	260	—	—	150,206	—	—

We did not observe a time trend in GSI ($r^2 = 0.003$, $P > 0.05$). However, a significant positive relationship existed between GSI and female length (Fig. 3), in which length accounted for about 40% of the variation in GSI ($r^2 = 0.39$, $P < 0.05$; $GSI = 0.06SL - 4.30$). There was no significant weight asymmetry between left and right ovaries ($t = 2.10$, $P > 0.05$, $n = 17$), but weight differences of as much as 22 g were measured.

Fecundity ranged from 28,416 to 168,196 ova (mean = 71,401, SD = 36,171, $n = 17$) (Table 1). Mean relative fecundity was 261 ova/mm SL (SD = 103.2) and 163 ova/g TW (SD = 42.3). Total fecundity varied significantly as a function of female length ($r^2 = 0.67$, $P < 0.05$; fecundity = $0.0004SL^{3.40}$) (Fig. 4) and as a function of total weight ($r^2 = 0.66$, $P < 0.05$; fecundity = $107.39TW^{1.56}$).

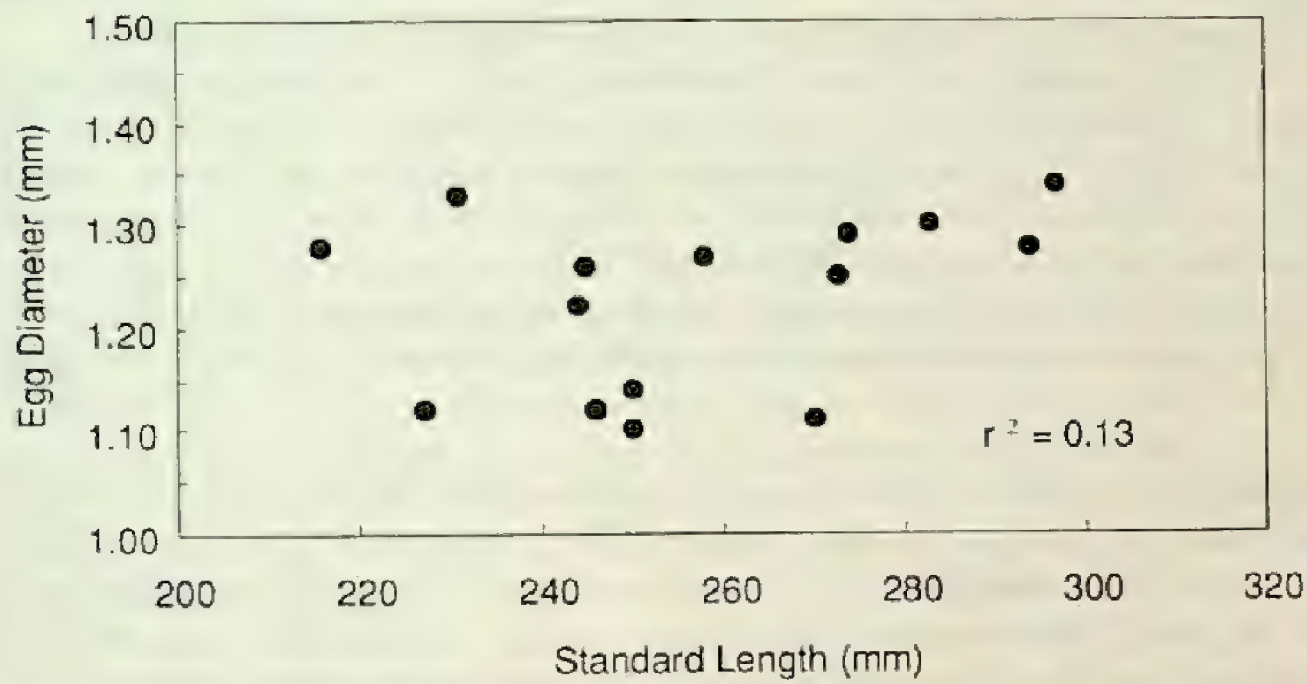


Figure 2. Relationship between mean egg diameter and splittail standard length.

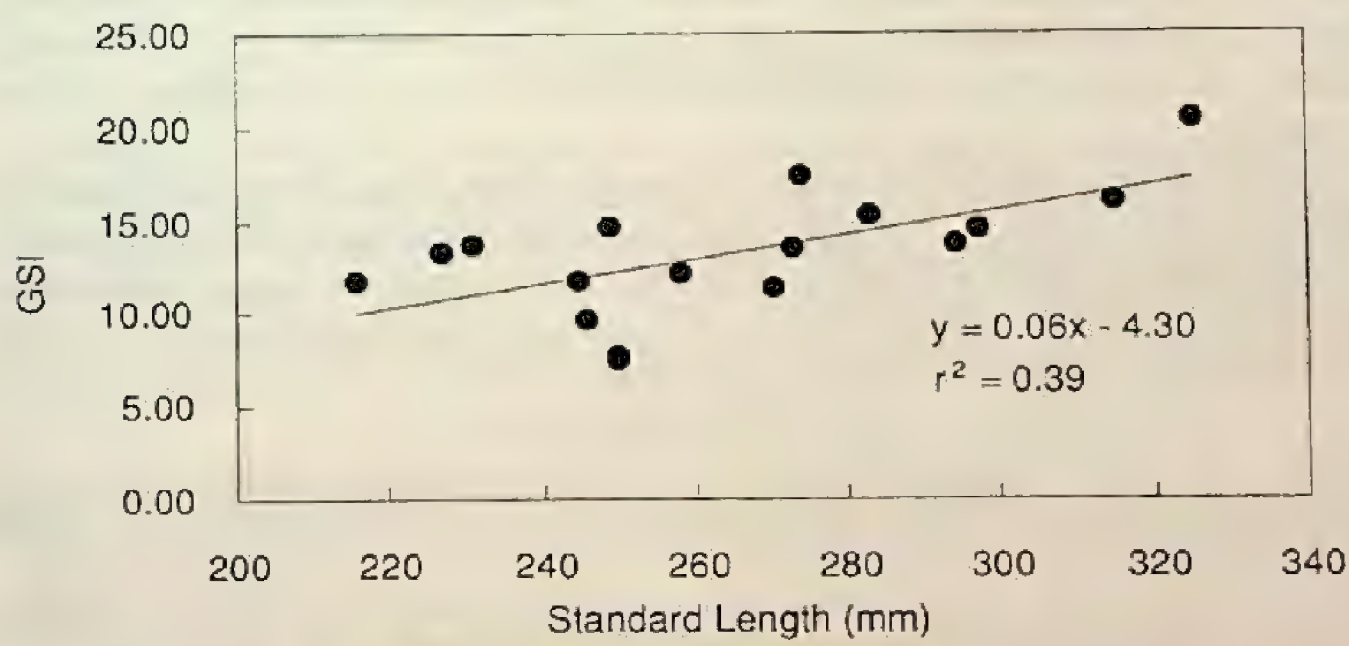


Figure 3. Relationship between GSI and splittail standard length.

DISCUSSION

The splittail is highly fecund compared to other native species. It averages 261 ova/mm SL and has a maximum fecundity >150,000 eggs. In contrast, delta smelt, *Hypomesus transpacificus*, an annual species also endemic to the Sacramento-San Joaquin Estuary, averages ≤ 35 ova/mm SL; maximum fecundity is only 2,500 eggs (Moyle et al. 1992). Maximum fecundity estimates for other species native to the estuary include 10,932 for Sacramento sucker, *Catostomus occidentalis* (Burns 1966a); 17,730 for Sacramento pikeminnow, *Ptychocheilus grandis* (Burns 1966b); 26,000 for hitch, *Lavinia exilicauda* (Nicola³ 1974); and 124,720 for Sacramento perch, *Archoplites interruptus* (Mathews⁴ 1962). However, Murphy (1950) reported a Sacramento blackfish, *Orthodon microlepidotus* (collected from Clear Lake, Lake County, California) with an estimated 350,000 eggs.

The high fecundity of splittail is necessary because it exhibits no parental care (Wang² 1986), prefers to deposit eggs on flooded terrestrial vegetation (Caywood¹ 1974) that can often become exposed to air when floods recede, and lives in a highly dynamic environment that is subject to dramatic annual fluctuations in the quantity of suitable spawning habitat. High fecundity and small egg size are common strategies for reproduction in harsh environments (Bagenal 1978).

Our estimates of splittail fecundity differ from those of 2 earlier studies (Table 1). We were able to obtain data for all 8 splittail examined by Caywood¹ (1974), but only for 8 of 20 splittail examined by Daniels and Moyle (1983), for statistical comparison (Table 1). After a significant ANOVA ($F = 37.57$; $df = 2, 30$; $P < 0.05$), Tukey's multiple comparison test indicated that mean eggs/mm SL reported by Daniels and Moyle (1983) was significantly higher than that found by the other studies (Fig. 4). No GSI or egg size data are available for splittail examined for fecundity in the earlier studies. Caywood¹ (1974) reported GSI values within the range of the current study, but for splittail other than those for which fecundity was estimated. Daniels and Moyle (1983) only reported a maximum GSI (18%), which was surprisingly lower than the maximum reported by the other 2 studies considering their significantly higher fecundity estimates. Caywood¹ (1974) did not measure egg size, whereas Daniels and Moyle (1983) measured an insufficient number of egg diameters to use in analysis.

The difference in fecundity estimated between Daniels and Moyle (1983) and the other 2 studies is striking. To further investigate the discrepancy, we estimated GSI for the Daniels and Moyle (1983) data (Table 1) based upon our egg weights and the splittail length-weight relationship. The resulting GSI estimates ranged from 37% to well over 50%. However, Daniels and Moyle (1983) reported a maximum GSI of

³ Nicola, S.J. 1974. The life history of the hitch, *Lavinia exilicauda* Baird and Girard, in Beardsley Reservoir, California. California Department of Fish and Game, Inland Fisheries Administrative Report No. 74-6.

⁴ Mathews, S.B. 1962. The ecology of the Sacramento perch, *Archopolites interruptus*, from selected areas of California and Nevada. M.A. Thesis, University of California, Berkeley, California, USA.

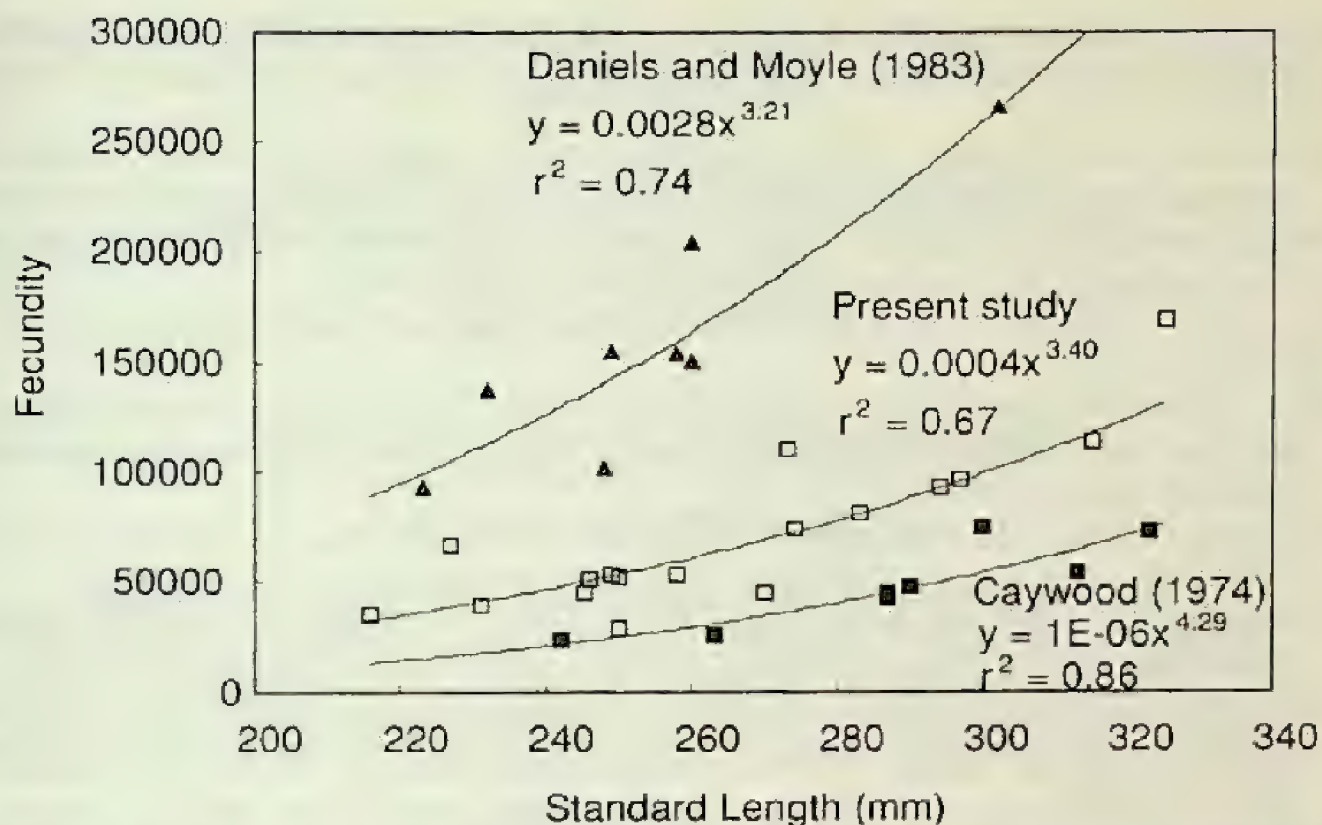


Figure 4. Relationship between fecundity and splittail standard length from 3 independent studies. Daniels and Moyle's estimates (1983) are significantly higher than those of the 2 other studies ($P < 0.05$).

only 18%. If these data are correct, average egg size of the Daniels and Moyle (1983) splittail would have to be at least 50% smaller (mass or volume) than that of our study. Daniels and Moyle (1983) estimated fecundity for splittail collected throughout the calendar year. Splittail collected before the spawning season may have included ova that never matured and were not spawned. However, it seems unlikely that at least 50% of splittail eggs do not mature and are not spawned. If correct, the significant difference in splittail fecundity reported by Daniels and Moyle (1983) may reflect regional or annual natural variability.

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PREY SELECTION BY BARN OWLS USING ARTIFICIAL NEST BOXES

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We evaluated the diets of barn owls, *Tyto alba*, attracted to artificial nest boxes in order to assess their potential as a means of controlling Botta's pocket gophers, *Thomomys bottae*. Pocket gophers were the most important prey of barn owls, based on mass and on frequency of occurrence in diets, and barn owls appeared to prefer juveniles. Barn owls switched from eating California voles, *Microtus californicus*; deer mice, *Peromyscus maniculatus*; and house mice, *Mus musculus*, during winter to eating mostly gophers, especially juveniles, during spring and summer. A pair of nesting barn owls ate an average of 22 gophers per month. It is unclear whether installation of nest boxes can increase barn owl densities enough to control gophers through predation alone. Barn owls, however, may play a role in an integrated approach to gopher management by slowing population recovery following treatment with rodenticides, thereby reducing the frequency of rodenticide use.

INTRODUCTION

Barn owls, *Tyto alba*, have received considerable attention because of their potential to control rodent pests (Derting and Cranford 1982, Duckett 1982, Muñoz and Murúa 1990, Ingels 1992). Diet studies have shown that barn owls feed almost exclusively on rodents (Schwartz and Bleich 1985, Marti 1992, Ingels 1995). Barn owls are limited by availability of nesting cavities but readily use artificial nest boxes (Moore et al., in press), so installation of nest boxes may increase numbers of breeding barn owls (Marti 1992). Further, barn owls seem to exhibit a low degree of territoriality, so several breeding pairs might be concentrated in a relatively small area (Smith et al. 1974).

Botta's pocket gopher, *Thomomys bottae*, is a serious rodent pest in California. In recent years farmers in the Central Valley have installed hundreds of nest boxes to attract barn owls, primarily in hopes of controlling rodent pests, especially gophers (Moore et al., in press). Barn owl diets, however, vary geographically, and gophers usually are not their most frequently eaten prey (Marti 1992, Ingels 1995). To control gopher numbers, barn owls must eat enough of them to counter reproduction and

immigration. Our objective was to assess the diets of barn owls attracted to nest boxes in order to evaluate their potential as a means of controlling gophers.

METHODS

We studied barn owl diets in San Joaquin County, California during the 1996 nesting season. We randomly selected 10 growers in the Lodi Grape Growing District who had installed 38 nest boxes that were used by barn owls. Nineteen of these nest boxes were used for nesting, as evidenced by observations of nestling barn owls or broken egg shells, and the remainder were used as roost sites. Crops within 100 m of each nest box consisted of vineyards, orchards, alfalfa, or fallow land. In November 1995, before nesting began in January, we removed and discarded all regurgitated pellets found in or near nest boxes. At approximately 5-week intervals after 1 January 1996, we collected all pellets found beneath the 38 nest boxes and adjacent roost sites. Thus, pellets collected on each date were deposited since the last collection and represent prey eaten during that time interval. At the termination of the study in August 1996, we collected all pellets found in each nest box, which represented additional prey eaten from January through July that had not been recorded during the 5-week collections.

We broke each pellet apart and identified prey remains by comparison with mammal and bird specimens in the Museum of Wildlife and Fisheries Biology, University of California, Davis. To determine temporal changes in diets, we calculated percent frequency of occurrence of prey items among pellets that were found beneath nest boxes during each collection interval. To estimate the number of gophers eaten by a pair of owls during the nesting season, we counted the number of right mandibles of gophers in all pellets found beneath or in each of the 19 boxes that were used by nesting pairs of barn owls. To determine size-dependent predation on gophers and its relationship to season, we measured the lengths of right mandibles of gophers identified in pellets during the 5-week collection intervals.

Body mass and mandible length (both log transformed) are linearly related in the northern pocket gopher, *Thomomys talpoides*, (Janes and Barss 1985), so we used linear regression to determine this relationship for *T. bottae*. We measured right mandible length (mm) and body mass (g) of 59 specimens in the Museum of Wildlife and Fisheries Biology.

We calculated product-moment correlation coefficients to determine if prey frequencies of occurrence varied independently of one another, and if gopher size varied independently of gopher frequency of occurrence, among 5-week collection intervals. Prey frequencies of occurrence were arcsine-transformed before statistical analysis.

RESULTS

We collected 621 pellets from 38 boxes. Botta's pocket gophers and California voles, *Microtus californicus*, were the most frequent prey in barn owl diets (Table 1). Deer mice, *Peromyscus maniculatus*, and house mice, *Mus musculus*, also were

Table 1. Percent frequency of occurrence of prey items of Botta's pocket gophers in diets of barn owls in San Joaquin County, California, as determined at approximately 5-week intervals from January to August 1996.

	1 Feb	2 Mar	7 Apr	11 May	20 Jun	3 Aug	Mean
Gopher	32	30	33	60	55	83	42
California vole	51	42	40	30	35	13	42
Deer mouse	22	32	26	17	10	6	18
House mouse	17	30	21	10	7	3	15
Bird	4	2	8	1	10	13	5
Rat	4	3	6	1	1	0	3
n	254	111	42	89	94	31	Total = 621

common in diets. Birds and rats, *Rattus* spp., were eaten occasionally (2–5% of pellets) and rabbits, *Sylvilagus* spp.; insects; crayfish; bats; and moles, *Scapanus* spp., were eaten rarely (< 2% of pellets).

Gophers were eaten most often during spring and summer, whereas voles were eaten most often during winter. Occurrence of gophers in diets among the 6 collection intervals was significantly negatively correlated with occurrence of each of the other major prey: voles ($r = -0.95$, $P < 0.01$), deer mice ($r = -0.92$, $P < 0.01$), and house mice ($r = -0.92$, $P < 0.01$). In contrast, paired correlations among voles, deer mice, and house mice all were positive and either were significant (deer mice versus house mice, $r = 0.98$, $P < 0.001$) or approached significance (voles versus deer mice, $r = 0.77$, $P < 0.10$; voles versus house mice, $r = 0.76$, $P < 0.10$).

Body masses of 59 museum specimens of *T. bottae* ranged from 23 to 225 g, with a median of 126 g. Mass was strongly related to mandible length ($r^2 = 0.85$, $P < 0.001$), so we estimated the body mass of gophers eaten by barn owls from the regression equation $\log(\text{mass}) = 3.49 \log(\text{mandible length}) - 2.73$. Median mandible length of gophers eaten was 19.7 mm, corresponding to an estimated body mass of 61 g (Table 2). Because the median body mass of adult *T. bottae* exceeds 90 g for females and 120 g for males (Daly and Patton 1986), barn owls evidently were eating mostly juvenile gophers. Median size of gophers consumed, however, changed seasonally; in general, smaller gophers were eaten during spring and summer (Table 2). Among the 6 collection intervals, gopher size was significantly negatively correlated with percent occurrence of gophers in the diet ($r = -0.82$, $P < 0.05$).

The minimum number of gophers eaten per nesting pair of owls, as indicated by number of right mandibles, varied greatly (range = 13–433) and averaged 152 gophers for the nesting season, or about 22 gophers per month per pair. This represents a minimum figure, since barn owls may regurgitate pellets away from nest boxes where we did not find them (Evans and Emlen 1947).

Table 2. Body mass of Botta's pocket gophers in diets of barn owls in San Joaquin County, California, as determined at approximately 5-week intervals from January to August 1996.

	<u>1 Feb</u>	<u>2 Mar</u>	<u>7 Apr</u>	<u>11 May</u>	<u>20 Jun</u>	<u>3 Aug</u>	<u>Mean</u>
Median (g)	69	90	79	52	67	53	61
Range (g)	28-212	39-231	41-182	20-199	25-194	22-162	20-231
n	55	24	13	82	66	37	Total = 277

DISCUSSION

Barn owls in our study area fed mostly on gophers and voles. Gophers, however, are larger than voles (Jameson and Peeters 1988); thus, on the basis of both body mass and frequency of consumption, gophers appear to be the most important prey of barn owls. An inverse relationship between prey items in the diet over time indicates prey switching (Todd and Keith 1983, Van Vuren 1991). Prey switching is common in barn owls, which often focus on 1 or a few prey species at a time and switch to alternate prey as availability changes (Taylor 1994). In our study, barn owls switched from eating voles and mice during winter to a diet dominated by gophers during spring and summer. Voles may have been especially vulnerable during winter because herbaceous vegetation was too sparse to provide adequate cover early in the growing season. The inverse relationship between gopher size and occurrence in the diet suggests that the increased consumption of gophers during spring and summer resulted from owls focusing on juveniles. Availability of juveniles may be important; spring and summer is the time of peak reproduction in gophers in the Central Valley (Howard and Childs 1959, Loeb 1990). Further, juvenile gophers may have been preferred because of their size (Colvin and McLean 1986). Barn owls in Oregon preferred gophers with a mass of 33-64 g (Janes and Barss 1985). Behavior also may have played a role; juvenile gophers probably are especially vulnerable when dispersing above ground (Howard and Childs 1959, Loeb 1990). Juvenile Townsend moles, *Scapanus townsendii*, were highly susceptible to barn owl predation when dispersing above ground during spring and summer (Giger 1965).

At a minimum, a pair of nesting barn owls ate an average of almost 1 gopher per day. Whether this rate is sufficient to limit gopher numbers depends on gopher densities and rate of reproduction, as well as barn owl densities. Gopher densities of 20/ha in non-irrigated fields in the Central Valley are typical (Howard and Childs 1959), and densities in irrigated fields can be as high as 120/ha (Miller 1957). One female produces 6-20 young per year, depending on whether the field is irrigated (Loeb 1990). Assuming a female gopher density of 15/ha (Howard and Childs 1959), a reproductive rate of 6 young/female (Loeb 1990), all produced during the barn owl nesting season, and no other predators, barn owl densities of 1 pair per 2 ha in non-irrigated fields would be necessary to remove the annual reproductive output of gophers. Although barn owls will nest in relatively close proximity to each other (Smith et al. 1974), it is unknown if installation of artificial nest boxes can maintain such high densities. Even higher densities would be needed in irrigated fields.

In conclusion, barn owls appear to prefer gophers, especially juveniles, and they consume numerous gophers during the nesting season. However, whether barn owls can achieve densities sufficient to limit gopher numbers through predation alone remains uncertain. Nonetheless, barn owls may play an important role in an integrated approach to gopher management by reducing the frequency of rodenticide application (Derting and Cranford 1982). Although vertebrate predators usually cannot control numbers of an abundant prey, if prey numbers are first reduced by other means, predators may keep numbers low for a time (Trout and Tittensor 1989, Newsome 1990, Kay et al. 1994). Thus, once gopher numbers have been reduced with rodenticides, barn owl predation may slow the recovery of the gopher population, thereby lengthening the interval until rodenticides are needed again. Barn owls are sensitive to availability of sufficient prey (Marti 1992), so the presence of adequate vole populations may be important as a source of alternate prey to maintain barn owl numbers (Pearson 1971). Predation by barn owls may be particularly effective at delaying population recovery of gophers through reproduction, because of their apparent preference for juveniles. Further, depleted rodent populations can be restored rapidly through immigration (Van Vuren and Smallwood 1996); thus, barn owl predation on dispersing juveniles may be especially important in reducing the rate of reinvasion of a depopulated field from surrounding areas.

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ADULT AND JUVENILE ANADROMOUS SALMONID MIGRATION TIMING IN CALIFORNIA STREAMS

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When oil spills occur in the vicinity of coastal stream mouths, chemical dispersants cannot be used if smolt or adult stages of salmonids are present. To aid planners in preparing for oil spills, monthly arrival times of spawning runs of adult anadromous salmonids and months when smolts outmigrate to the ocean at tidal inlets of California streams were compiled (Appendix 1). Only streams that empty directly into the ocean or Humboldt, San Francisco, or San Pablo bays are presented. The data were compiled from various publications and from interviews conducted with field biologists having personal knowledge of individual streams. Historical observations were included in cases where recent surveys have not been done or were inconclusive about the presence of salmonids. These data can also be used by resource managers who are reviewing projects that may affect water flow in the lower parts of coastal streams, or near tidal inlets, when migrating salmonids, adults or smolts, may be present.

Chinook salmon, *Oncorhynchus tshawytscha*; coho salmon, *O. kisutch*; and steelhead, *O. mykiss*, are the most abundant anadromous salmonids in California. The coastal cutthroat trout, *O. clarki clarki*, is also anadromous and found in small coastal streams from the Eel River in Humboldt County north to Alaska (Emmett et al.¹ 1991). Information on its migrations was not detailed enough for inclusion in Appendix 1. Pink salmon, *Oncorhynchus gorbuscha*; chum salmon, *Oncorhynchus keta*; and sockeye salmon, *Oncorhynchus nerka*, do not normally spawn in California and are not included.

Chinook salmon have 4 distinct runs in California. Runs are named after the season when they migrate from the ocean to fresh water for spawning: fall, late-fall, winter, and spring. The Sacramento River is used by all runs and is the only one to have late-fall and winter runs. Some other rivers also have more than 1 run. Most small coastal rivers have only a fall run.

Coho salmon have only 1 run and are most common in small coastal streams. They are not found in the Sacramento or San Joaquin River systems, but are found in small numbers in other tributaries to San Francisco Bay.

¹Emmett, R.L., S.A. Hinton, S.L. Stone, and M.E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in West Coast estuaries, volume II: Species life history summaries. ELMR Report No. 8, NOAA/NOS Strategic Environmental Assessments Division, Rockville, Maryland, USA.

Steelhead spawning migrations are complicated by the fact that adult steelhead may be entering rivers to spawn or, unlike salmon, returning to the ocean following spawning. As a result, steelhead may be migrating year-round in larger rivers. Most California streams have only a winter steelhead run that migrates for spawning during fall, winter, and early spring. In addition to the winter run, the Klamath, Eel, and Mad rivers also have summer runs migrating for spawning during spring, summer, and early fall (Busby et al.² 1996). Unlike most rivers, the largest run in the Klamath River is the fall run.

Detailed information about outmigrating smolts is incomplete for most small coastal rivers and in many cases shows only the time when smolts entered the estuary, not the time when they actually migrated into the ocean. Residence time in an estuary is a function of species, run, and stream conditions. Generally, stream residence times are <1 year for chinook salmon, ≤ 1.5 years for coho salmon, and 1–6 years for steelhead. Unlike migrating adult salmonids that are often the target of anglers, smolts are usually small and difficult to see and attract no special attention. Generally, outmigration patterns are the same as for the geographically nearest stream of a similar size for which information is shown.

For most species of salmonids, the peak spawning migration is in fall and winter. Most chinook salmon smolts outmigrate in spring and summer. Coho salmon smolts outmigrate from March to July and usually peak between mid-April and mid-May.

Some runs of salmonids are listed as threatened or endangered. Sacramento River winter-run chinook salmon are listed by both the State of California and the Federal government as endangered (California Code of Regulations, Title 14; Federal Register, 50 CFR 17.11). Coho salmon in central California are listed by California as endangered and by the Federal government as threatened. Coho salmon in southern Oregon and northern California are listed by the Federal government as threatened. Coastal cutthroat trout and summer-run steelhead are species of special concern (Moyle et al.³ 1989). For a detailed listing of the status of coho for West Coast states and selected rivers, see Weitkamp et al.⁴ (1995). See Busby et al.² 1996 for a complete listing for steelhead.

Probably the most important environmental factors affecting the timing for both returning adult salmon migration and smolt outmigration, especially for small coastal streams, is the condition of the river mouth and the amount of runoff from rainfall.

² Busby, P.J., T.C. Wainwright, G.J. Bryant, L. Lierheimer, R.S. Waples, F.W. Waknitz, and I.V. Lagomarsino. 1996. Status review of West Coast steelhead from Washington, Oregon, Idaho, and California. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-27.

³ Moyle, P.B., J.E. Williams, and E.D. Wikramanayake. 1989. Fish species of special concern of California. Contract Number 7337, California Department of Fish and Game, Inland Fisheries Division, Sacramento, California, USA.

⁴ Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Department Commerce, NOAA Technical Memorandum NMFS-NWFSC-24.

Many small coastal streams are closed entirely by sand bars that build across their mouths during periods of low rainfall and mild ocean conditions in summer. Barnhart and Young⁵ (1986) describe conditions for the Mattole River that are typical of conditions for many small coastal streams and stress the importance of estuaries to salmonids. The first major upstream migrations coincide with large increases in stream flow, especially in streams with low summer flows (Shapovalov and Taft 1954). Heavy rainfall and subsequent runoff removes the bar and provides a pathway for migrating fish. Freshwater runoff may provide olfactory clues to attract migrating adult salmon into the stream. Heavy runoff also serves to 'flush' smolts trapped in an estuary into the ocean.

The largest populations of salmon are found in the Klamath and Central Valley river systems. Migrating adult spawners can exceed 100,000 fish in the Klamath River and 150,000 in Central Valley rivers (PFMC⁶ 1995). The Smith and Eel rivers also support large numbers of salmon, but in many of the streams in Appendix 1, the number of spawning adults is low, perhaps fewer than 100 fish.

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⁵ Barnhart, R. and D. Young. 1986. Mattole Estuary habitat management plan. Sikes Act Project Number CA-056-WHA-A4. Available in the Humboldt Room, Humboldt State University Library, Arcata, California, USA. Call letters: SH222C3B371985.

⁶ PFMC (Pacific Fishery Management Council). 1995. Review of 1994 Ocean Salmon Fisheries. Portland, Oregon, USA.

Appendix 1. Timing of adult salmonid spawning migration and smolt outmigration to the ocean for 143 California streams, listed from north to south. Key to symbols and abbreviations: CO-coho salmon, SH-steelhead, CH-chinook salmon, A-adult, A_F -adult fall run, A_{LF} -adult late-fall run, A_w -adult winter run, A_{sp} -adult spring run, A_{su} -adult summer run, S-smolts, *-indicates peak run time, R.-river, G.-gulch, C.-creek.

Stream	Sp.	Month											
		<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Smith R.	CO					A^*	A^*	A		S	S^*		
	SH				A_w	A_w^*	A_w^*	A_w^*	A_w^*	A_w			
	CH	A_{su}	A_{su}	A_{su}								A_{su}	A_{su}
Klamath R.	CO		A_F	A_F^*	A_F								
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						
Redwood C.	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						
Little R.	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
Mad R.	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
Jacoby C. ^a	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
Freshwater C. ^a	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
Elk R. ^a	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
Eel R.	CO		A	A^*	A^*	A	A						
	SH		A_w	A_w	A_w	A_w	A_w^*	A_w^*	A_w^*	A_w	A_w		
	CH	A_F	A_F^*	A_F									A_F
	CO		A	A^*	A^*	A	A						

Month

Stream	Sp.	<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Eel R.	SH		Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w
		Λ_{su}	Λ_{su}	Λ_{su}	Λ_{su}				Λ_{su}	Λ_{su}	Λ_{su}	Λ_{su}	Λ_{su}
		S	S	S	S					S	S	S	S
	CH			Λ_F	Λ_F	Λ_F	Λ_F			Λ_{sp}	Λ_{sp}	Λ_{sp}	Λ_{sp}
										S	S	S	S
Mattole R.	CO			A	A*	A*	A	A		S	S*	S	
	SH				Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	Λ_w			
		S	S										S
	CH			Λ_F	Λ_F	Λ_F					S	S	S
Whale Gulch	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Bear Harbor	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Jackass C	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Usal C.	CO			A	A	A*	A*	A		S	S	S*	S*
	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Cottaneva C.	CO			A	A	A*	A*	A		S	S	S*	S*
	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Hardy C.	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Juan C.	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Howard C.	CO			A	A	A*	A*	A		S	S	S*	S*
	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
DeHaven C	CO			A	A	A*	A*	A		S	S	S*	S*
	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Wages C.	CO			A	A	A*	A*	A		S	S	S*	S*
	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Chadbourne G.	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S
Kibesillah C.	SH					Λ_w	Λ_w	Λ_w	Λ_w	Λ_w	S*	S*	S

Appendix 1. (continued)

Stream	Sp.	Month											
		<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Abalobadiah C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Ten Mile R.	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
	CH			Λ_F^*	Λ_F^*	Λ_F							
								S	S	S'	S'	S	
Mill C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Virgin C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Pudding C.	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH				Λ_w	Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Noyo R.	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH				Λ_w	Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
	CH			Λ_F^*	Λ_F^*	Λ_F							
								S	S	S'	S'	S	
Hare C.	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Digger C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Mitchell C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Jughandle C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Caspar C. ^b	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Doyle C. ^b	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Russian G.	CO			Λ	Λ	Λ^*	Λ^*	Λ					
								S	S	S'	S'	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S'	S'	S	
Big R.	CO			Λ	Λ	Λ^*	Λ^*	Λ					
									S	S'	S'	S	

Appendix I. (continued)

<u>Stream</u>	<u>Sp.</u>	<u>Month</u>											
		<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Big R.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
	CH			A _F *	A _F *	A _F							
								S	S	S*	S*	S	
Little R.	CO			A	A	A*	A*	A					
								S	S	S*	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Dark G.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Albion R.	CO			A	A	A*	A*	A					
								S	S	S*	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Big Salmon C.	CO			A	A	A*	A*	A					
								S	S	S*	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
	CH			A _F *	A _F *	A _F							
								S	S	S*	S*	S	
Little Salmon C.	CO			A	A	A*	A*	A					
								S	S	S*	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
	CH			A _F *	A _F *	A _F							
								S	S	S*	S*	S	
Navarro R.	CO			A	A	A*	A*	A					
								S	S	S*	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
	CH			A _F *	A _F *	A _F							
								S	S	S*	S*	S	
Greenwood C.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Elk C.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Mallo Pass C.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Irish G.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Alder C.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Brush C.	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	
Garcia R.	CO			A	A	A*	A*	A					
								S	S	S*	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w			
								S	S	S*	S*	S	

Appendix 1. (continued)

Stream	Sp.	Month											
		<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Arena C.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Schooner G.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Fish Rock G.	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Gualala R.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*		
	SH					Λ_w	Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w		
								S	S	S^*	S^*	S	
Fort Ross C.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Miller C.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Stockhoff C.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Russian G.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Russian R.	CO				A	Λ^*	Λ^*	Λ					
									S	S^*	S^*	S	
	SH			Λ_w	Λ_w	Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
							S	S	S	S^*	S^*	S	
	CH	Λ_F	Λ_F	Λ_F	Λ_F	Λ_F							
							S	S	S	S^*	S^*	S	
Scotty C.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Salmon C.	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Estero Americano	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	
Estero de San Antonio	CO			A	A	Λ^*	Λ^*	Λ					
								S	S	S^*	S^*	S	
	SH					Λ_w	Λ_w^*	Λ_w^*	Λ_w	Λ_w			
								S	S	S^*	S^*	S	

Appendix 1. (continued)

Stream	Sp.	Month											
		<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Walker C.	CO			A	A	A*	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Lagunitas C.	CO			A	A	A*	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Glenbrook C.	CO			A	A	A*	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Muddy Hollow C.	CO			A	A	A*	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Coast C.	CO				A	A*	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Pine Gulch C.	CO				A	A*	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Redwood C. (Pt Bolinas)	CO				A	A*	A	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Redwood C. (Pt Bonita)	CO				A	A	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Sacramento R. ^a	SH				A _w	A _w	A _w *	A _w *	A _w	A _w			
	CH	A _{SU}	A _{SU}	A _{SU}		A _F	A _F	A _F	A _F	A _F	A _{SU}	A _{SU}	A _{SU}
Rodeo C. ^c	CO				A	A	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S
Sonoma C. ^e	CO				A	A	A*	A					
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S*	S

Appendix 1. (continued)

Stream	Sp.	<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>Month</u>							
						<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Petaluma R. ^c	CO				A	A	A*	A		S	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S	
									S	S	S*	S	
Novato C. ^c	CO				A	A	A*	A		S	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S	
									S	S	S*	S	
Miller C. ^c	CO				A	A	A*	A		S	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S	
									S	S	S*	S	
Gallinas C. ^c	CO				A	A	A*	A		S	S*	S	
	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S	
									S	S	S*	S	
Arroyo Corte	CO				A	A	A*	A		S	S*	S	
Madera del										S	S*	S	
Presidio ^c	SH					A _w	A _w *	A _w *	A _w	A _w	S*	S	
									S	S	S*	S	
San Pedro C.	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Denniston C.	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Frenchmans C.	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Pilarcitos C.	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Lobitos C.	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Tunitas C.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
San Gregorio C.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Pomponio C.	CH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Pescadero C.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	
Gazos C.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w	A _w	A _w *	A _w *	S*	S	
							S	S	S*	S*	S*	S	

Appendix 1. (continued)

<u>Stream</u>	<u>Sp.</u>	<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>Month</u>							
						<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Whitehouse C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Ano Nuevo C.	SH					A _w	A _w S	A _w S*	A _w S*	A _w S*	S*	S	
Waddell C.	CO				A	A	A	A		S*	S*	S*	S
	SH				A _w	A _w	A _w S	A _w S	A _w S*	A _w S*	A _w S*	S	
Scott C.	CO				A	A	A	A		S*	S*	S*	
	SH				A _w	A _w	A _w S	A _w S	A _w S*	A _w S*	A _w S*	A _w S	
San Vicente C.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Liddell C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Yellow Bank C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Wilder C.	SH					A _w	A _w	A _w	A _w S*	A _w S*	S*	S	
San Lorenzo R.	CO				A	A	A	A		S*	S*	S	
	SH				A _w	A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Arana Gulch C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Soquel C.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Aptos C.	CO					A	A	A		S*	S*	S*	S
	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Pajaro R.	CO				A	A	A	A		S*	S*	S*	S
	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Salinas R.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Carmel R.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
San Jose C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Gibson C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	

Appendix I. (continued)

Stream	Sp.	<u>A</u>	<u>S</u>	<u>Q</u>	<u>N</u>	Month							
						<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Malpasos C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Garrapata C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Rocky C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Bixby C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Little Sur R.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Big Sur R.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Partington C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Lime C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Big C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
LimeKiln C.	CH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Mill C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Prewitt C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Plaskett C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Willow C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Salmon C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
San Carpoforo C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Arroyo de la Cruz	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Little Pico C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Pico C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
San Simeon C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Santa Rosa C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Villa C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	
Toro C.	SH					A _w	A _w S	A _w S	A _w S*	A _w S*	S*	S	

Appendix 1. (continued).

Appendix 1. (continued).		Month											
Stream	Sp.	<u>A</u>	<u>S</u>	<u>O</u>	<u>N</u>	<u>D</u>	<u>J</u>	<u>F</u>	<u>M</u>	<u>A</u>	<u>M</u>	<u>J</u>	<u>J</u>
Morro C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Chorro C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Los Osos C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Islay C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Coon C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
San Luis Obispo C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Pismo C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Arroyo Grande C.	SH					A _w	A _w	A _w	A _w *	A _w *			
							S	S	S*	S*	S*	S	
Santa Ynez R. ^d	SH				A _w	A _w	A _w	A _w	A _w	A _w	A _w		
Ventura R.	SH		A _w	A _w	A _w	A _w	A _w	A _w *	A _w *	A _w	A _w	A _w	
Santa Clara R.	SH				A _w	A _w	A _w	A _w *	A _w *	A _w	A _w	A _w	
Arroyo Siquet	SH					A _w	A _w	A _w *	A _w *				
Malibu C.	SH					A _w	A _w	A _w *	A _w *				
San Mateo C.	SH					A _w	A _w	A _w *	A _w *				
Santa Margarita C. ^e	SH						A _w	A _w	A _w *	A _w *			

^a These streams flow into Humboldt Bay, which opens to the ocean through permanently maintained jetties. Smolts use the bay as an estuary before entering the ocean.

^b Young-of-the-year coho salmon and steelhead, 25–35 mm total length, have been observed in the nearshore environment. Downstream migrant trapping data in Caspar and Doyle creeks indicate these fish form small schools and move from 1 stream to another to rear. Stream habitat typing indicates that the fish move from the stream with poor rearing habitat to the one with a better rearing environment.

^c These streams flow into San Francisco Bay (including San Pablo Bay). Information on smolt migration timing is based on the time they leave the stream or river, rather than the time they leave the bay for the ocean.

^d The Pacific slope of the Santa Ynez Mountains from Gaviota to Rincon has numerous small streams, many of which have runs of steelhead.

^e Steelhead have been observed in both San Mateo Creek and Santa Margarita Creek (Greg Bryant, National Marine Fisheries Service, personal communication).

**OCCURRENCE OF THE RED PIKE-CONGER,
CYNOPONTICUS CONICEPS (JORDAN AND GILBERT,
1881) (PISCES: MURAENESOCIDAE), IN THE GULF OF
CALIFORNIA**

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The red pike-conger, *Cynoponticus coniceps*, also known as "morenocio bio-bio" or "culebra blanca," is a benthic, piscivorous fish that reaches 1 m in length and inhabits warm, shallow, coastal waters (10–100 m depth) with sand and mud bottoms (Jordan and Evermann 1896, Smith 1995).

On 26 January 1984, 2 specimens of the red pike-conger (Fig. 1) were captured with a commercial shrimp net near El Desemboque, between Santo Tomas and Cabo Tepoca, Gulf of California, Sonora, Mexico (30°34'N, 113°01'W). The specimens were taken at a depth of 33 m on a sandy bottom.

The previously known distribution of the red pike-conger was from Mazatlan, Sinaloa (type locality) and Cabo San Lucas, Baja California Sur, Mexico, to the coast of Colombia (Jordan and Evermann 1896, Kumada 1937, Ramírez-Hernández 1976, Smith 1995). The specimens of red pike-conger from El Desemboque represent the northernmost record of the species and the 1st occurrence of the species in the upper Gulf of California. The range of this species is thus extended about 1,055 km farther north than previously reported.

The specimens were identified by the following combination of diagnostic characteristics (Jordan and Evermann 1896, Smith 1995): body robust, moderately elongate; tail compressed; mouth large, upper jaw extending well beyond the eye; anterior nostril short and tubular; posterior nostril situated at level of the eye; gill

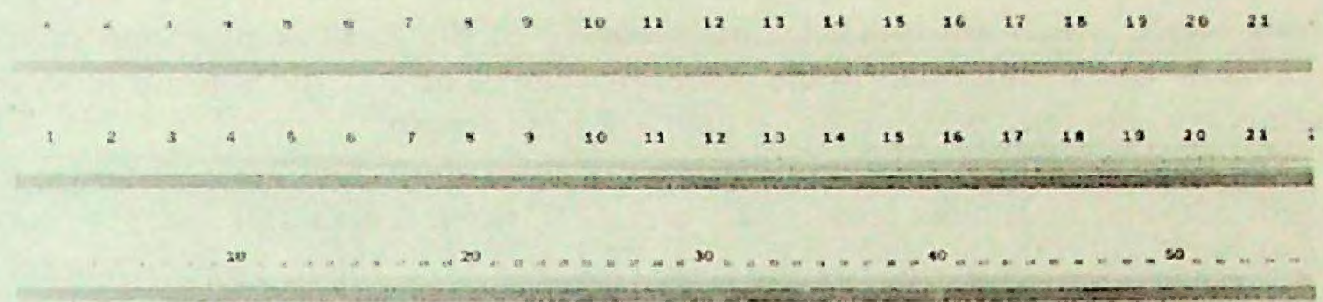
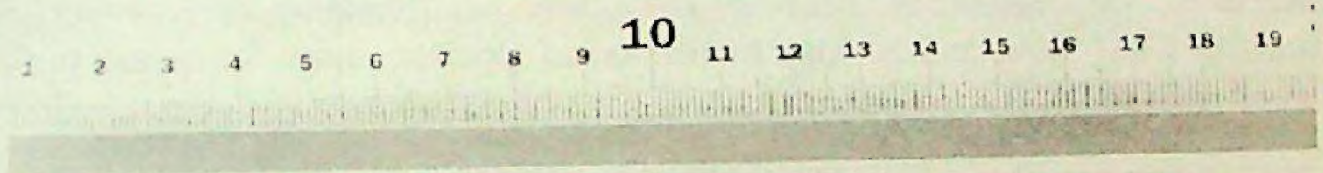
**A****B**

Figure 1. (A) Specimen of red pike-conger (550 mm total length) collected in El Desemboque, Gulf of California, Mexico (26 January 1984). (B) Lateral view of the head and anterior trunk region of the same specimen.

cleft large, inferior, rather oblique; vomer with a median row of about 15 very large, strong teeth, which are much compressed; tip of the teeth angular and directed backwards and with a nick on the posterior edge; 1 or 2 of the anterior teeth only slightly tricuspidate; pectoral more than 1/2 head length.

The body measurements in millimeters of the 2 specimens are as follows: total length 550 and 553, head length 74.1 and 77.9, trunk length 150 and 151, caudal length 332 and 333, preorbital distance 17.3 and 18.8, interorbital distance 11.5 and 12.0, eye diameter 8.6 and 9.0, and upper jaw length 31.1 and 33.0.

The color of the specimens as preserved in alcohol is coppery brown, being darker on the dorsum. Dorsal and anal fins are edged with black; pectorals fins are black.

The specimens are deposited in the ichthyological collections of the Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León (UANL-13370) and Facultad de Ciencias, Universidad Autónoma de Baja California (UABC-0010).

Our record of the red pike-conger in the upper Gulf of California may represent a case of geographical disjunction similar to those reported for other conger-like eels (*Anguilliformes*) in the eastern Pacific region (Walker 1960, McCosker and Rosenblatt 1995).

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